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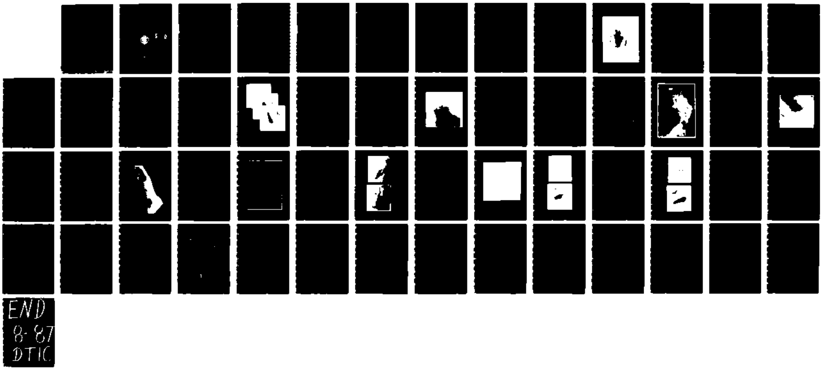

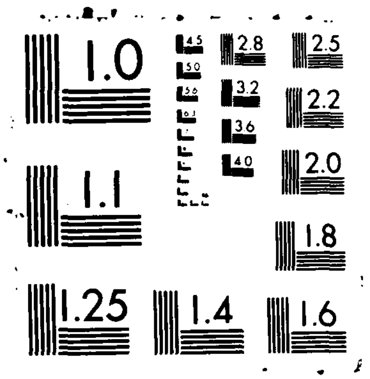
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# A TRIDENT SCHOLAR PROJECT REPORT

NO. 146

## ANALYSIS OF GLINT PATTERNS USING REMOTE SENSING TECHNIQUES



UNITED STATES NAVAL ACADEMY
ANNAPOLIS, MARYLAND

1987

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Satellite images from the NOAA-7 satellite of this region were enhanced and examined for correlation between surface structure in the shuttle photographs and thermal structure in the satellite images. A direct relationship exists between the two structures.

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# ANALYSIS OF GLINT PATTERNS USING REMOTE SENSING TECHNIQUES

A Trident Scholar Project Report

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# ABSTRACT

A laboratory simulation of the spiral eddies viewed from the space shuttle Challenger on the STS 41-G mission was constructed. The construction allowed for collection of quantitative data coincident with the recording of any surface structure on polaroid film. A spiral flow was introduced into a test region, and the spiral nature of the flow verified by the plot of horizontal current velocity measurements. No manifestation of this flow, however, was evident on the water's surface.

The unexpected results of the laboratory simulation provided the stimulus for a more in-depth study of the actual environmental conditions surrounding the presence of spiral eddies in the Levantine. Examination of the bathymetry revealed a direct relation between the generation and dissipation of spiral eddies, and the depth of the basin. Rotational motion of the eddies in this region is governed by the conservation of angular momentum.

Satellite images from the NOAA-7 satellite of this region were enhanced and examined for correlation between surface structure in the shuttle photographs and thermal structure in the satellite

images. A direct relationship exists between the two structures.

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# I. INTRODUCTION

## a. Background

On 5 October 1984 the space shuttle Challenger was launched from Kennedy Space Center on mission STS 41-G. On board for the first time was a trained oceanographer, Dr. Paul D. Scully-Power. During the eight day flight that focused on studying earth sciences, Scully-Power viewed the oceans and recorded his observations on the visible phenomena. In addition to nearly 50 pages of notes, the mission produced over 1700 hand-held photographs taken by Scully-Power (1986) and the shuttle crew. Among the more impressive discoveries recorded in the photos was the world-wide presence of sub-mesoscale eddy patterns. Figure 1 is a shuttle photograph taken on 7 October 1984. In the center of the photograph, north of the island of Crete is a field of eddies visible in a background of sunglint. Prior to the STS 41-G mission, synoptic and mesoscale variabilities in the ocean currents were the only scales of motion considered to be of importance to ocean dynamics. These larger features were considered the energetically dominant form of motion in the sea (Robinson, 1983), while sub-

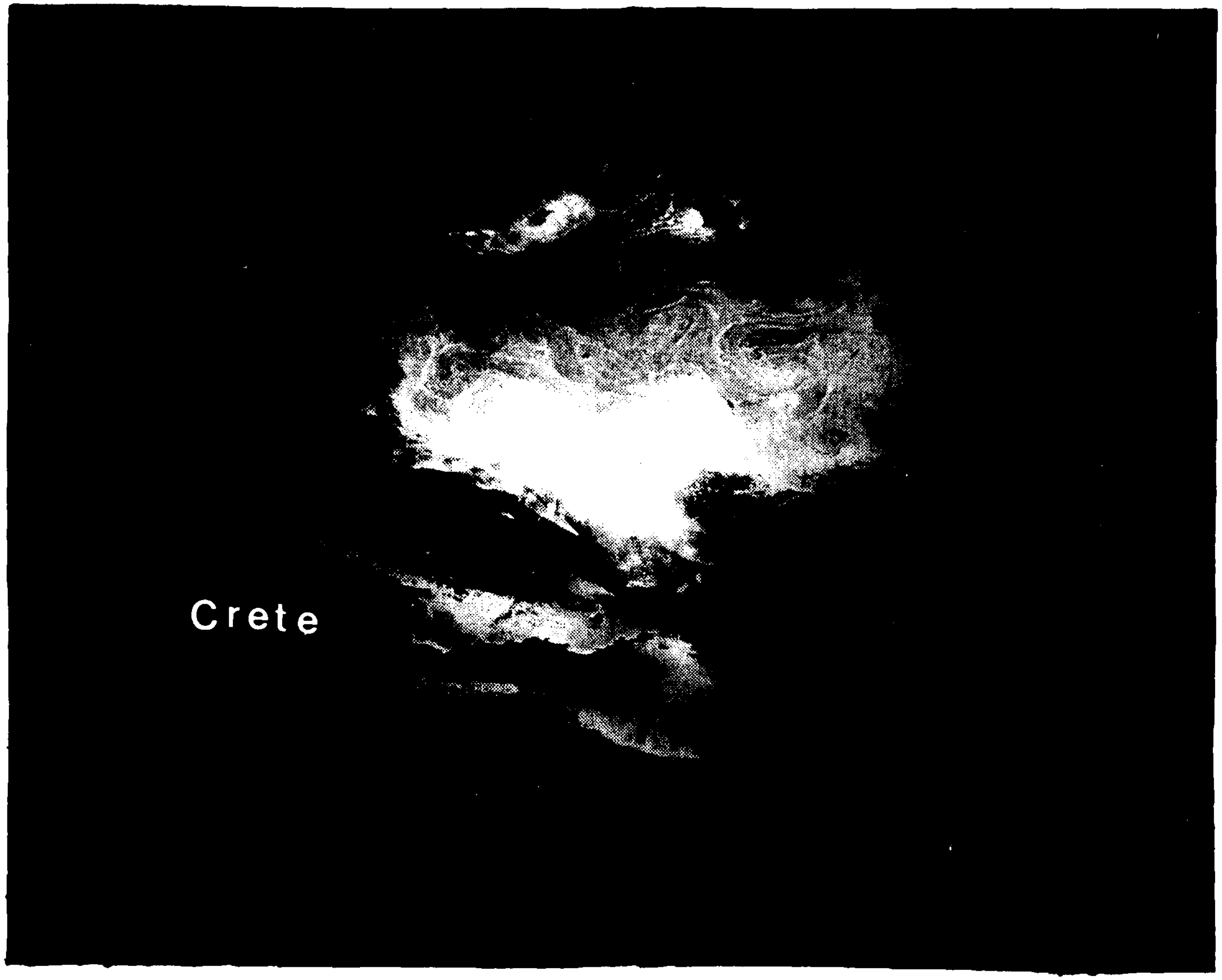



Figure 1 - Sub-mesoscale spiral eddies viewed in the sunglint northeast of the island of Crete. [From Scully-Power, 1986]

mesoscale "spirals" were believed to be isolated features occurring in specific locations. Photographs and observations from the Challenger mission, indicated otherwise. Spiral eddies were viewed from the shuttle so frequently throughout the world's oceans, they are now thought to be a fundamental element of ocean dynamics (Scully-Power, 1986).

b. Objectives

This research project was undertaken to further explore the characteristics of spiral eddies and the environmental conditions in which they occur. A region of study was chosen and an analysis of local oceanography conducted to determine the effect of bathymetry, ocean thermal structure and local wind stress on eddy patterns. Features in the shuttle photographs were compared to the thermal information in satellite images to detect any possible relationships. The purpose of this comparison was to determine:

1) if these eddy features are phenomena that occur in a shallow surface layer of water, and are susceptible to change with variations in local meteorology, or

2) if these eddies are more persistent features.

c. The Location of the Study

The shaded area in Figure 2 represents the Levantine Basin, the area from Crete south to the northern coast of Africa. The Levantine was selected as the region of study because of the substantial variability in the physical properties of the water. Observations from the space shuttle indicated a tendency for eddies to form in such regions (Scully-Power, 1986). Additionally, atmospheric conditions over this region produced several consecutive days of relatively cloud-free weather from 7 to 9 October. Shuttle photographs during these days depict persistent, detailed eddy structure with little or no cloud coverage. Because of the good visibility, thermal infrared imagery from the NOAA-7 polar orbiting satellite was available to complement the photographs taken on board the shuttle. Coincident with the shuttle mission, weather data were being recorded at both land-and ship-based observation stations in the area. The availability of shuttle pictures, satellite images and weather data in this region made the Levantine an appropriate area for investigation. The many islands surrounding this area were useful as geographic reference points for locating eddy features in the hand-held photographs and satellite imagery.

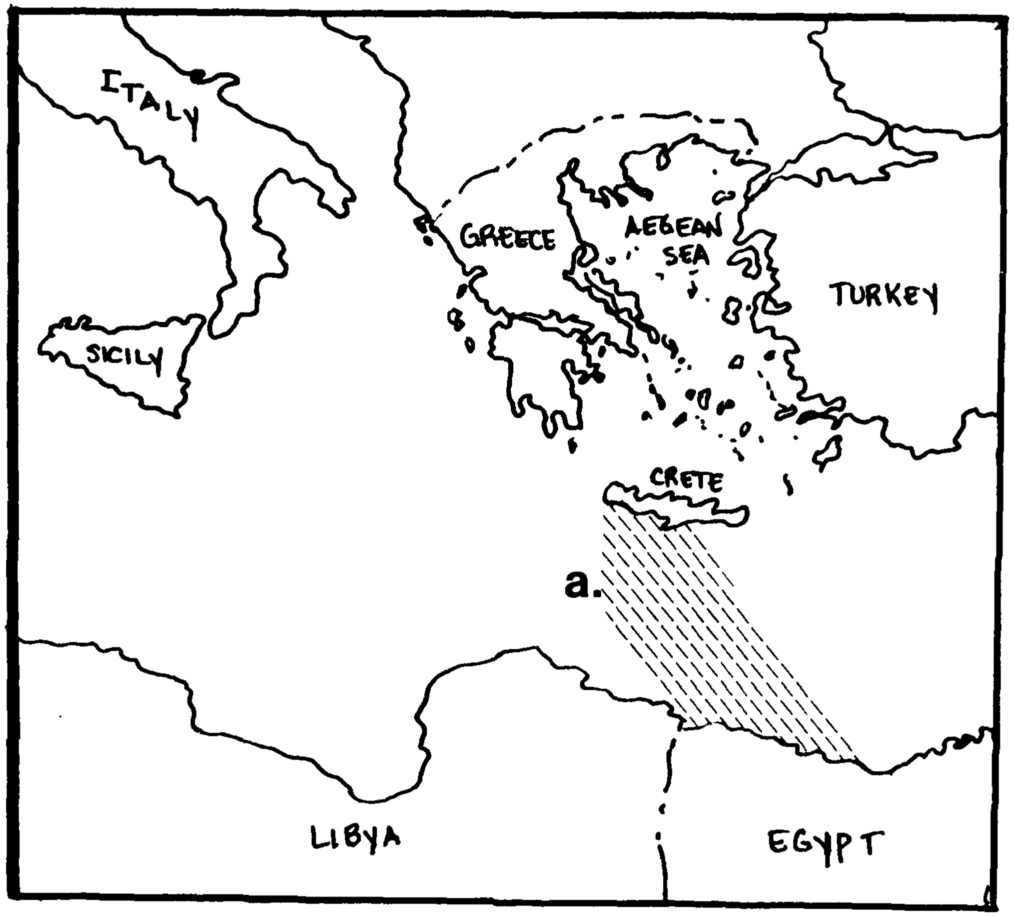



Figure 2 - The geographic region where study was conducted. The shaded area schematically represents the areal coverage of a mosaic of photographs taken on mission STS 41-G on 7 October 1984.

# II. DATA

## a. Photographic Instrumentation

The photography acquired during the STS 41-G shuttle mission was collected using three types of cameras. The majority of the photographs were taken with two NASA-modified Hasselblad 500 EL/M 70-mm cameras, equipped with additional 50-mm and 250-mm lenses. A larger 4 X 5 inch format Linhof Aero Technika 45 camera with interchangeable 50-mm and 250-mm lenses was used as the second source of photos. All windows in the shuttle orbiter were employed at differeent times during the mission, and could be used with either of the above two cameras. The flexibility afforded by the locations of the windows is depicted in Figure 3. Features could be photographed through the forward, aft and side-hatch windows at any angle, and through the overhead windows as the shuttle flew upside down. The positions of the windows also increased the frequency with which pictures could be taken: a series of eight Hasselblad photographs used in the research were taken at 4 to 8 second intervals. The third camera used was a cartographic, high precision camera also known as a large format camera (LFC). The LFC,

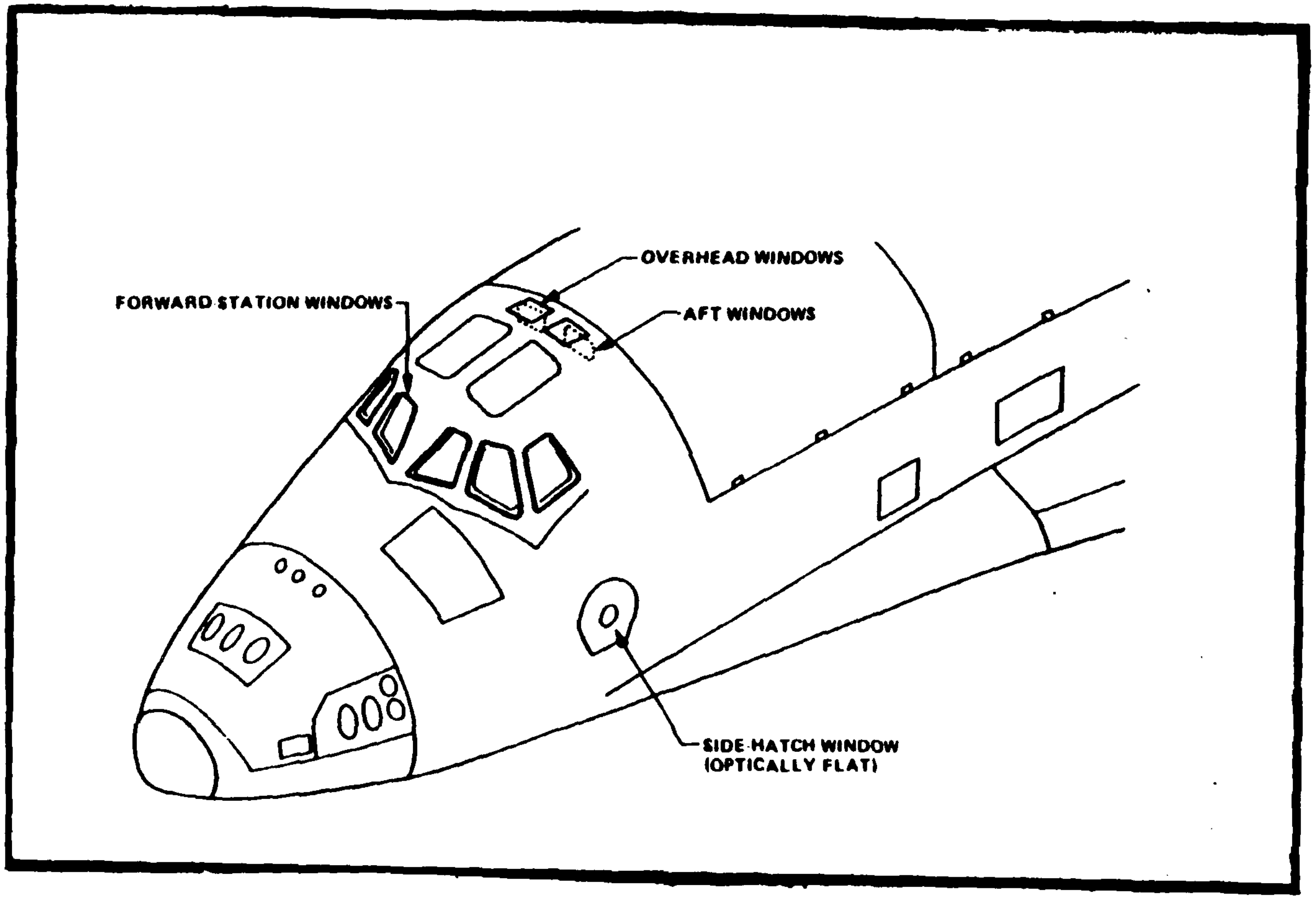



Figure 3 - Location of windows in shuttle orbiter. [From Hughes e . al., 1986]

being a nadir-looking camera, was more restricted in use. Because it was a cartographic camera, involving strict geometry of positioning, the dimensions of, and distances between, features could be determined to a specified degree of accuracy. The LFC produced an image 9 inches across track and 18 inches along track that corresponded to an area 90 nautical miles by 180 nautical miles when taken at an altitude of 120 nautical miles (Hughes et. al., 1986).

b. Production of Thermal Images

The thermal imagery used in this study is a product of the Advanced Very High Resolution Radiometer (AVHRR) carried on the NOAA-7 polar orbiting satellite. Three channels of the radiometer measure the intensity of radiation emitted from the earth in the infrared band. These measurements equate to temperatures, yielding an image of sea surface temperature distribution (Apel, 1983). Because these channels of the AVHRR measure the emitted thermal radiation, they operate during nighttime as well as daytime, when the two visible channels are also in operation. Since the AVHRR has a relatively large swath-width of 2850 km, the swaths on successive satellite orbits overlap, allowing for entire earth coverage in 14.1 orbits,

or one day and nighttime time period (Robinson, 1985).

c. Interpretation of Visual Observations

The optical phenomena that allows the spiral eddies to be observed in photographs is sunglint, the reflection of the sun from the water's surface. If the surface of the ocean is completely smooth, the sun will appear on it as if in a mirror: a disc of almost exact proportions. The surface of the ocean is never completely calm, thus the sun appears as a distorted, vaguely defined image, whose distortion is increased by the roughness of the ocean's surface and determined by the angle of the incoming sunlight (LaViolette, 1986). The position of this image on the surface changes according to the relative positions and geometry of the sun, nd the shuttle, and the state of the sea. As the shuttle proceeds in its orbit, the surface reflection, or bright area in each photograph moves with it, illuminating a different portion of the ocean's surface.

Eddies highlighted by such illuminated areas in a series of eight photographs were overlapped and connected to produce a mosaic. The three northmost photos of this mosaic are shown in Figure 4. A grid of latitude and longitude was navigated onto the mosaic using Crete and the coast of northern Africa

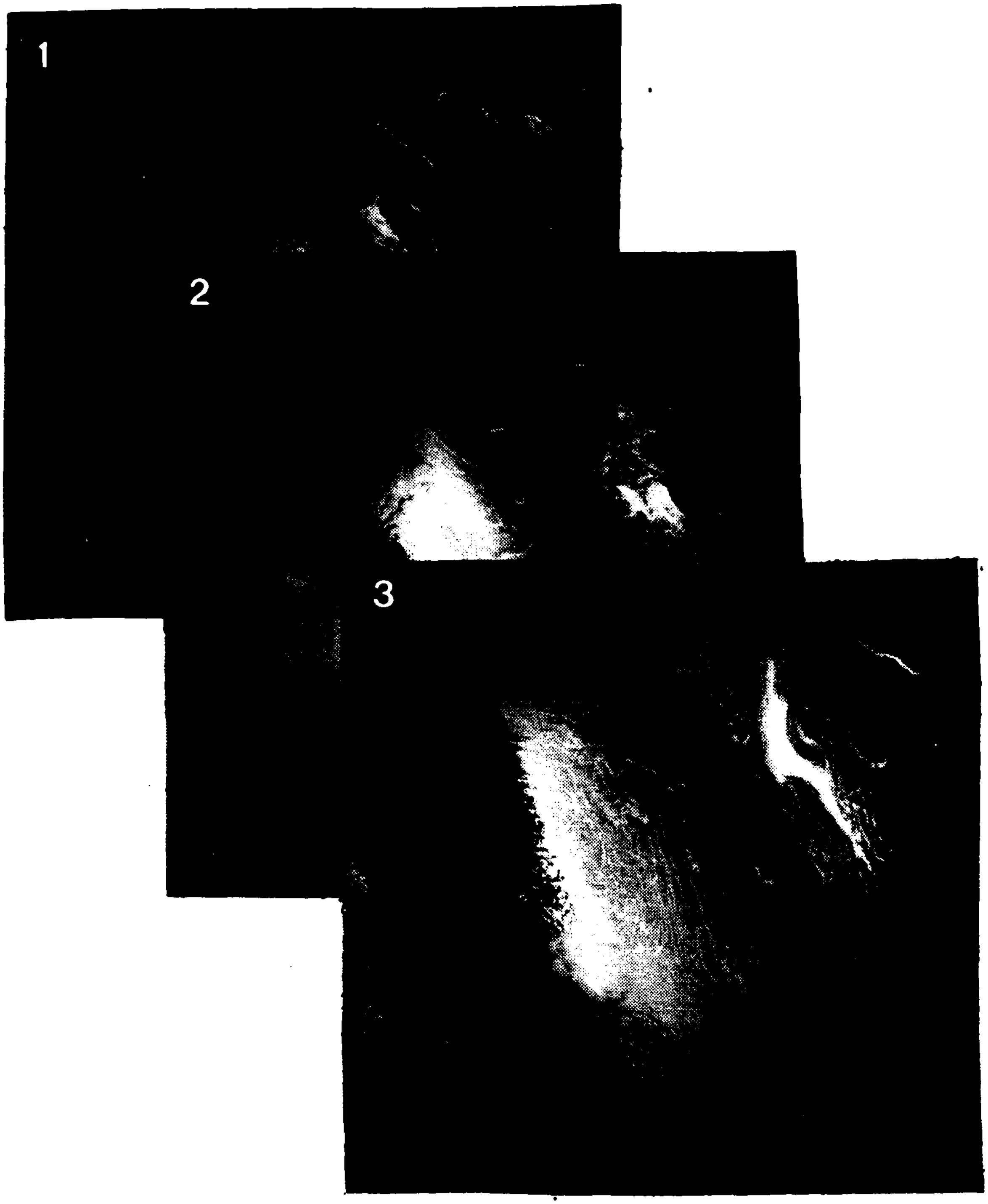



Figure 4 - Three northmost pictures in the mosaic of eight shuttle photographs. Crete is located in the upper right corner of frame (1). Frames (2) and (3) are navigated by co-locating identical features common to two photographs. [From Scully-Power, 1986]

as geographic reference points. This grid allowed the specific location of eddy features to be determined, even in the center photographs of the mosaic which contain no land features.

The streaks defining the spiral eddy patterns are noticeably more intense in the sunglint than the diffuse, less-bright areas surrounding them; without the sunglint they would not be easily discernible in the shuttle photographs. This indicates that the wave spectrum within the streaks is devoid of any high curvature capillary waves responsible for the surface roughness that determines most of the sunglint pattern. Floating debris, oil, biological remains--known collectively as surfactants--are known to reduce capillary wave activity (Scully-Power, 1986). An accumulation of surfactants along an eddy streak would suppress the surface roughness, permitting the sunglint to highlight those zones with respect to the surrounding surface pattern. In the non-glint regions of shuttle photographs, where the sun's rays are not reflected back to the camera, these streaks are dark, non-reflective zones. In a region closer to the specular point, some reflection occurs where the surface is rough. These streaks, however, are smoother and remain dark. Close to the specular point the same streaks become brighter

than the surrounding area since they represent zones where the water is smoother, and the sunlight is reflected more directly to the camera.

Dimensions calculated from the data of an LFC picture off the coast of Libya established characteristic measurements for sub-mesoscale (less than 100 km) spiral eddies. Spiral eddies have diameters between 10 and 15 km. The width of the streaks that define the eddies range from 105 meters to 375 meters, and the distance between the centers of these streaks was calculated to begin at approximately 500 meters, increasing to as much as 900 meters. While individual spirals typically maintain a uniform size between 10 and 15 km in diameter, they are interconnected by their constituent linear streaks into patterns several hundred kilometers in length (Scully-Power, 1986).

Close examination of the shuttle photographs used in this project reveals eddies forming in all areas of much dynamic activity--along boundary currents such as the Gulf Stream, and in confined seas such as the Mediterranean. The presence of these eddies does not seem to be governed by any specific order; rather, they appear to be positioned randomly in the field. As depicted in Figure 5 exceptions occur. Figure 5 shows a linear arrangement

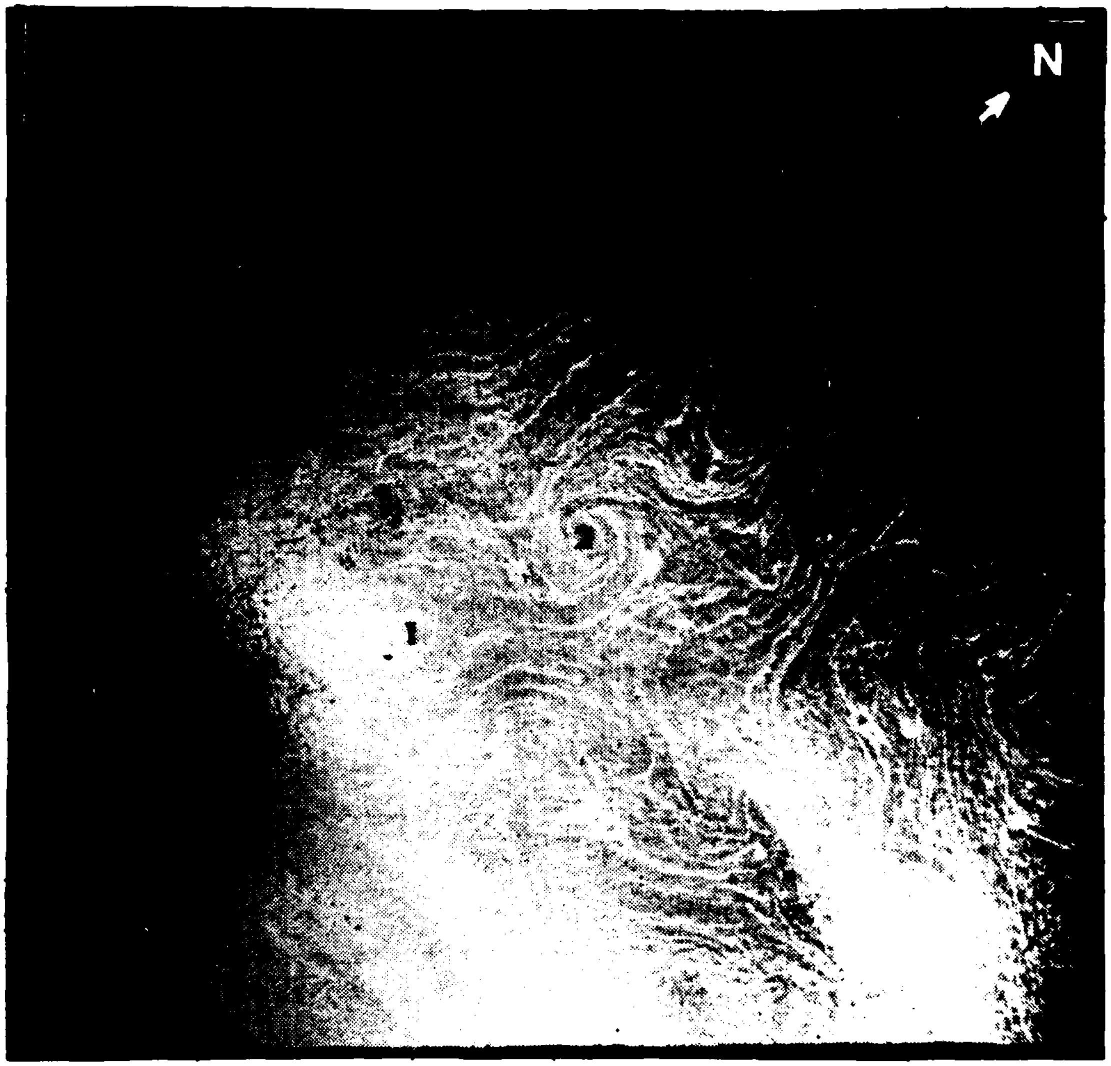



Figure 5 - Linear arrangement of eddies at positions 1, 2, 3
and 4 about 45 km north of the coast of Egypt.
[From Hughes et. al., 1986]

of eddies north of the coast of Egypt. This alignment was thought by Scully-Power (1984) to be a result of the eddies' recent generation and lack of sufficient time to move into a more random arrangement.

## III. ENVIRONMENTAL CONDITIONS

One of the most obvious characteristics of spiral eddies, according to Scully-Power (1986) is their cyclonic rotation--counterclockwise in the northern hemisphere, clockwise in the southern. Several explanations for the generation of eddy patterns exist. Although these explanations are usually applied to geostrophic eddies, they do make allowances for sub-mesoscale levels of motion (Robinson, 1983). These include conservation of potential vorticity, topographic effects, and the influence of surface wind stress. Eddy patterns in the eastern Mediterranean were studied to see which of these mechanisms were applicable.

### a. Conservation of Potential Vorticity

According to Apel (1983), energy conversions occur back and forth between eddies and the mean water flow in the ocean. These conversions are governed

by the equation describing the conservation of potential vorticity (Pond and Pickard, 1983):

$$\frac{\zeta + f}{D} = \text{constant} \qquad (1)$$

where $\zeta$ is the relative vorticity of the fluid mass

$f$ is the Coriolis parameter

$D$ is the depth of the water

Based on this relation, predictions can be made about vorticity changes when a parcel of water changes location. Since the changes in f are negligible in the area of study:

(1) if D increases, $\zeta$ increases and the water acquires more cyclonic (positive) rotation.

(2) if D decreases, $\zeta$ decreases and the water acquires more anti-cyclonic (negative) rotation.

The circulation pattern of the eastern Mediterranean (Figure 6) indicates that flow through the region depicted in the shuttle photographs originates north of Crete in the shallow Aegean Sea. Figure 7 shows that the water passes through the Strait of Kithira into the Levantine Basin. The water passes from a shallow area obstructed by many islands, through a restrictive channel, into an open basin of greater depth. To conserve potential vorticity along this

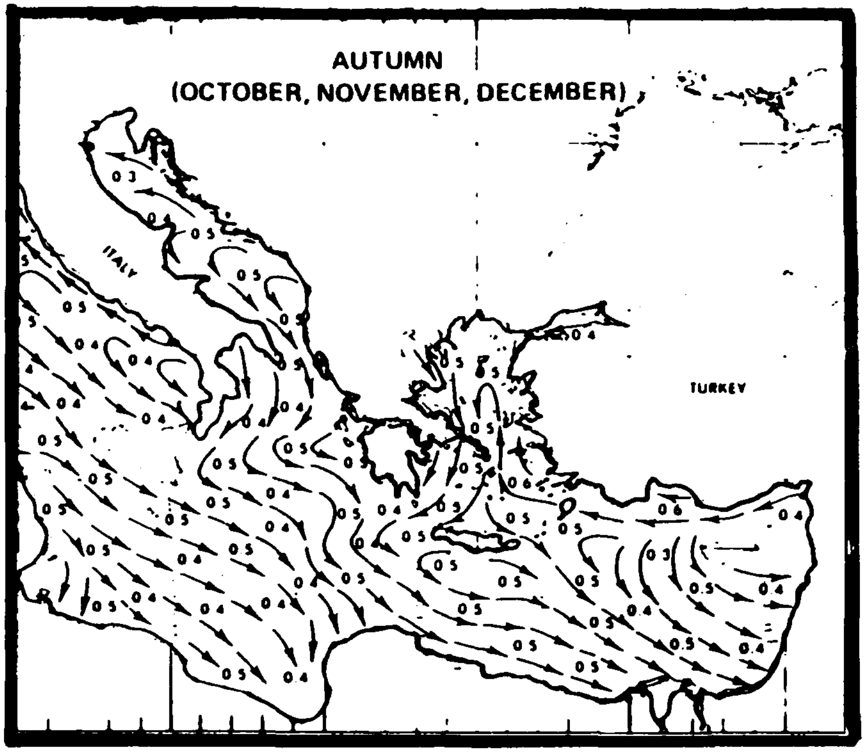



Figure 6 - Mean circulation pattern in the Mediterranean Sea.
[From U.S. Naval Oceanographic Office, 1980]

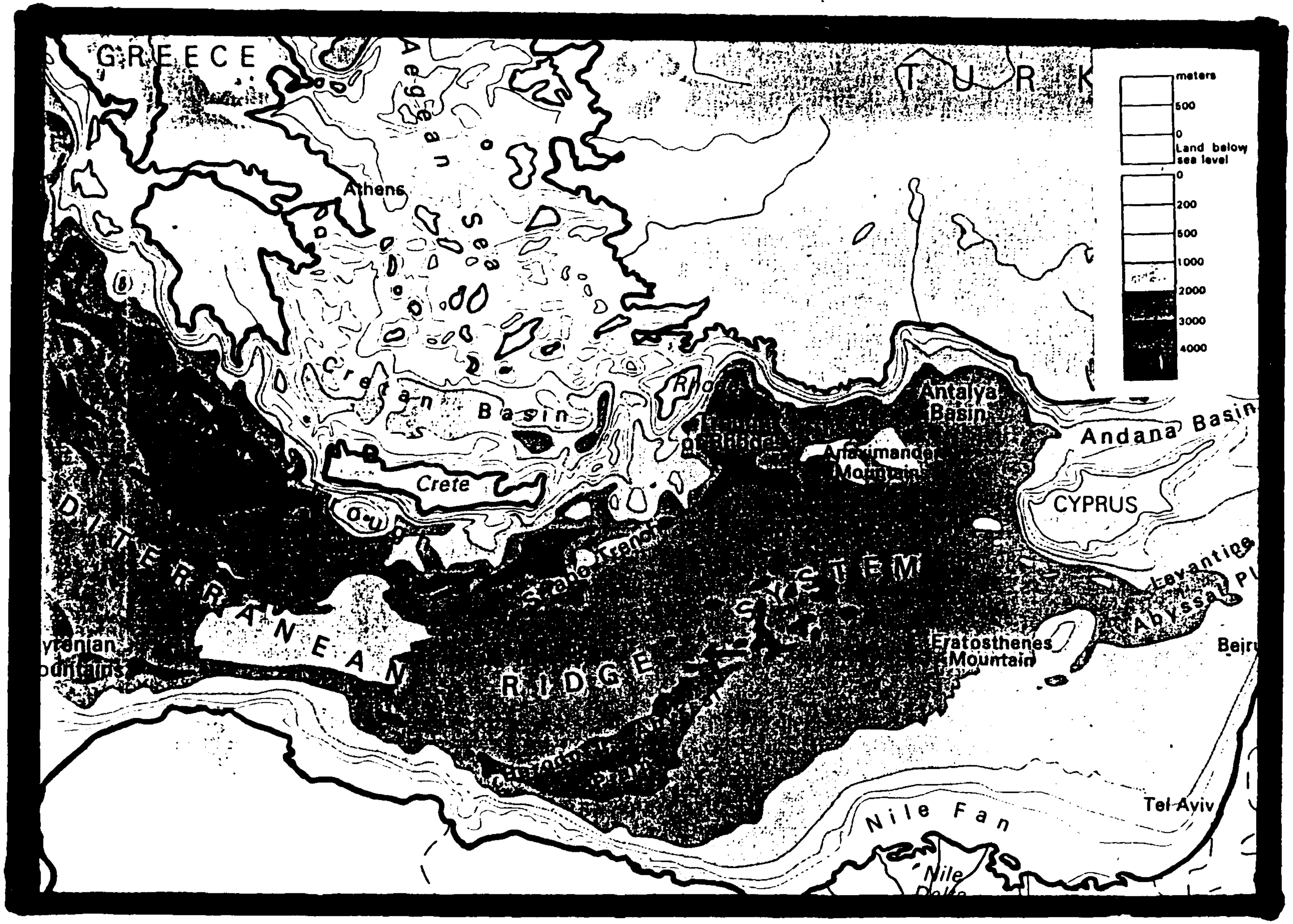



Figure 7 - Bathymetry of Mediterranean sea floor with regards to depth. [From Rand McNally,1977]

path, the water, as it enters the Mediterranean, would have to increase its positive sense of rotation in this flow, resulting in cyclonic motion as documented by Scully-Power (1986). Continuing South, the flow experiences a decrease in depth about 45 km from the African shoreline as the water moves up the continental slope. As depth decreases, a negative sense of rotation must increase to conserve potential vorticity. This negative sense of rotation suppresses the already existing positive rotation, thus surface eddy structure dissipates near the Egyptian coast. This result is confirmed by the shuttle photograph in Figure 8 which shows a distinct lack of structure in the sunglint near the Egyptian coast.

b. Bathymetry

Figure 9 is a schematic of the bathymetry in the Mediterranean Sea that reveals a chain of seamounts approximately 50 km from the southern coast of Crete. Current flow over seamounts has been shown to produce surface disturbances (Maskell, 1984). If these seamounts generate a disturbance, the disturbance would move so as to conserve potential vorticity. In this region, the vorticity is positive, inducing cyclonic motion which could develop into an eddy. The influx of water entering the Levantine

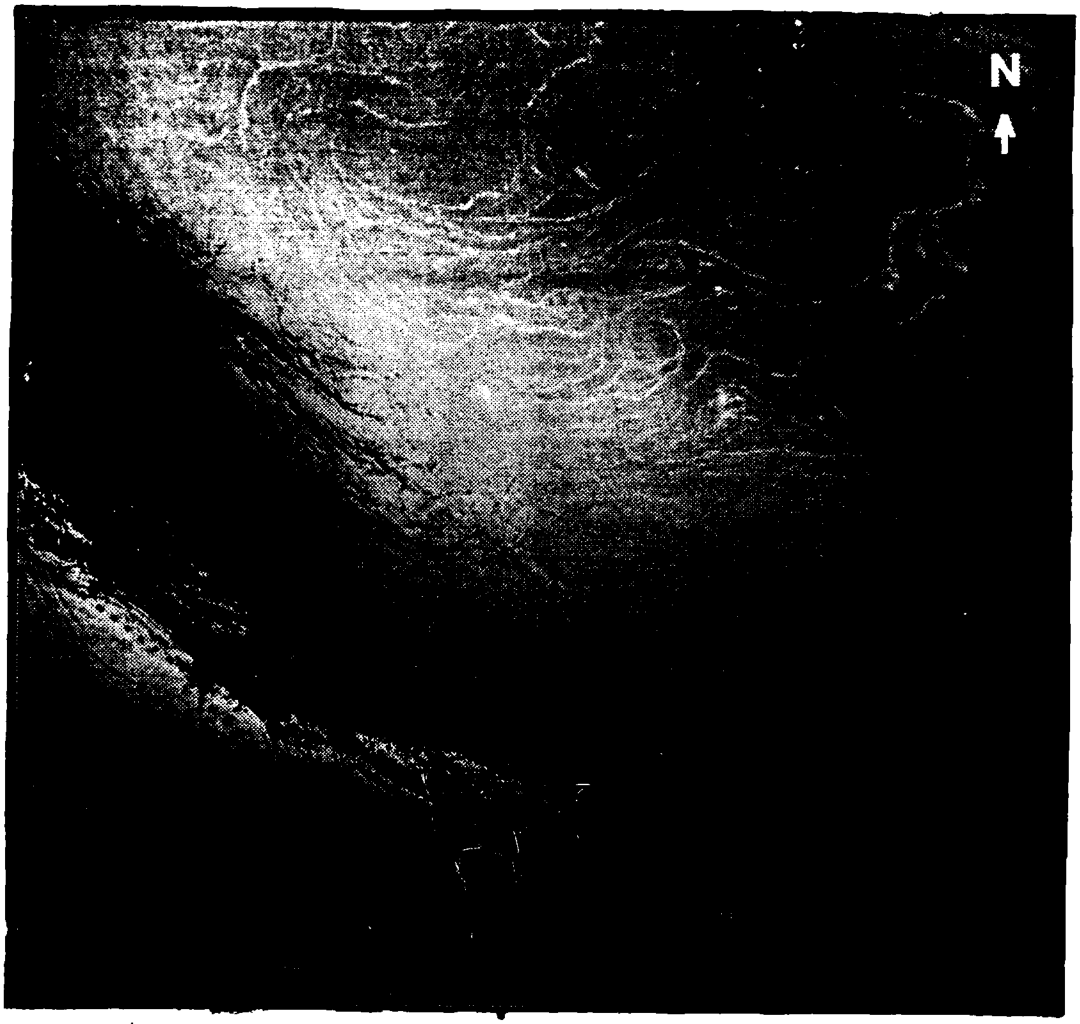



Figure 8 - Dotted line indicates the beginning of the continental slope, about 45 km off the coast of Egypt. Southeast or shoreward of the slope, the water contains little surface structure. [From Hughes et. al., 1986]

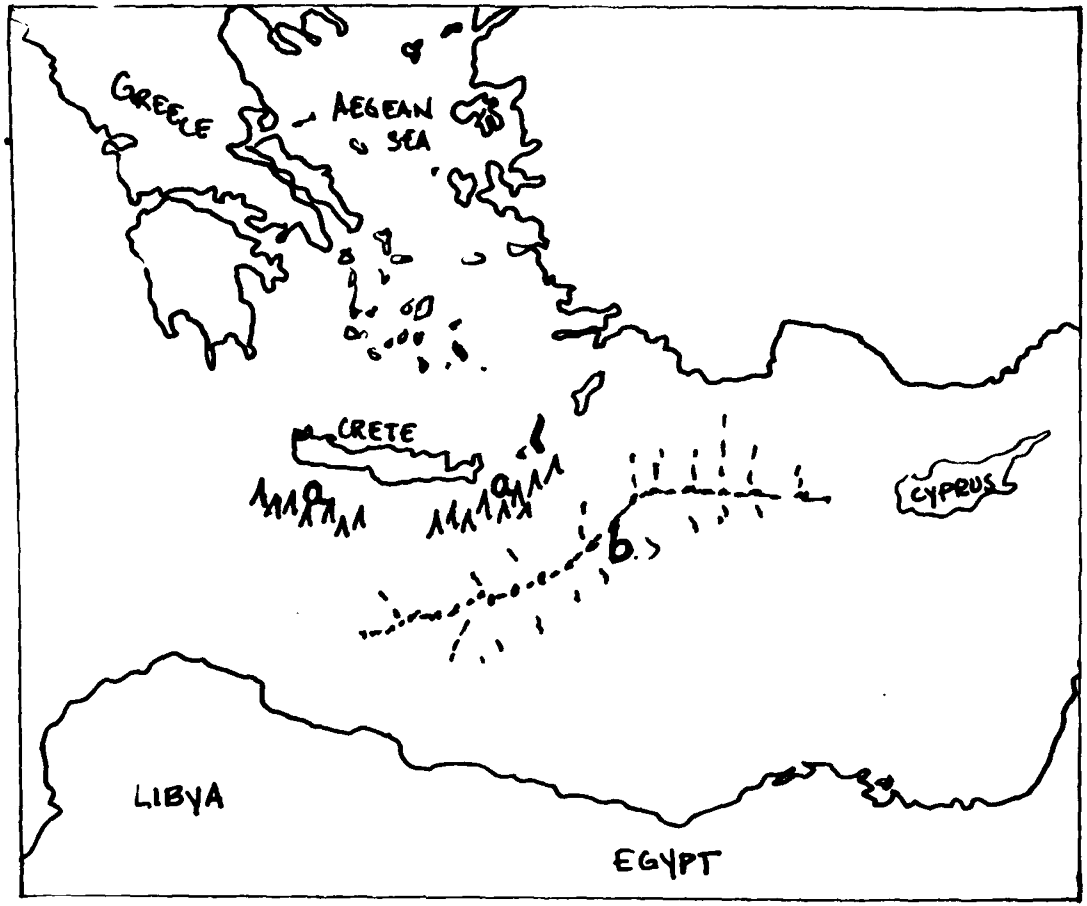



Figure 9 - Schematic of bathymetry of Levantine Basin. Seamounts at location (a) are potential source of eddy generation. (b) Mediterranean Ridge System. [From Rand McNally, 1977]

moves over these seamounts, creating a potential source of eddy generation.

The only other bathymetric feature with potential of causing a surface disturbance is the Mediterranean Ridge System. As seen in Figure 9, this system is oriented from Southwest to Northeast. The orientation of the spiral eddy field in the mosaic of shuttle pictures is Northwest to Southeast. This perpendicular relationship between the ridge system and eddy field indicates that patterns are not topographically related. Furthermore, the vertical cross-section of circulation in the eastern Mediterranean represented in Figure 10 reveals a surface current in the upper 75 to 300 meters of water flowing in the same general direction as the eddy alignment viewed in the mosaic. Underlying the surface layer is a deeper, more dense mass of cooler water which moves in the opposite direction. The surface layer, in which the eddy structures appear, is kept from interacting with the bottom topography by the underlying layer of cold water, thus should not contain a surface manifestation of bottom features.

c. Wind

As the shear force between the water surface

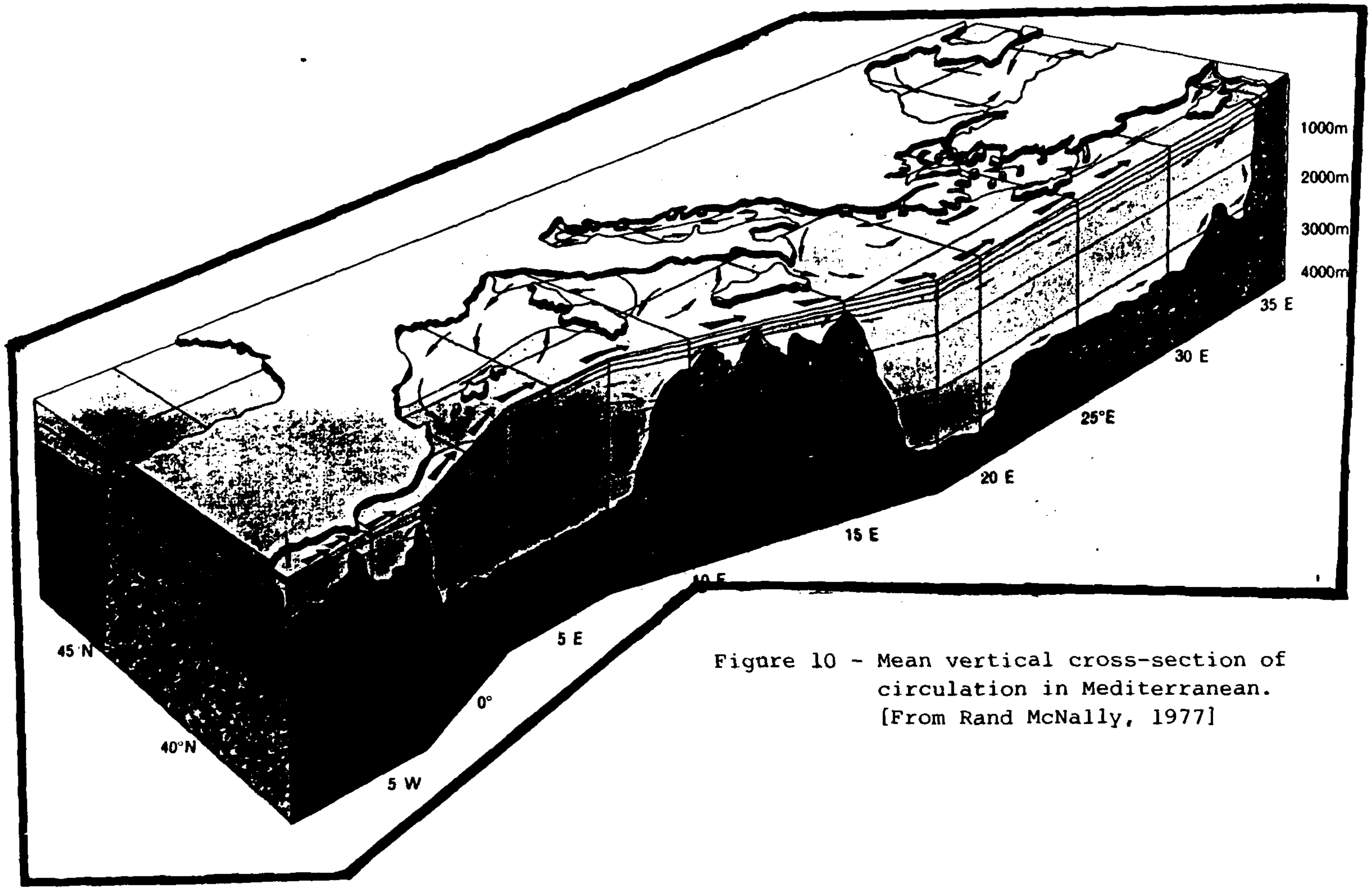



Figure 10 - Mean vertical cross-section of circulation in Mediterranean. [From Rand McNally, 1977]

and surface wind stress may produce surface structure, a meteorological analysis with emphasis on wind data was conducted for the region on 7 and 8 October. Figure 11 shows a plot of local wind data collected from land and ship-based weather stations. The end points of the arrows mark the location of the station; the three numbers on each arrow represent the time of data collection, true direction of wind, and wind speed, in meters per second, respectively. The plot indicates that local winds blow from the Northwest in the same direction as the orientation of the eddy fields. This data, supported by information from weather satellites, make it unlikely that the wind is causing any shear interaction that would govern eddy motion.

d. Sea Surface Temperature

Satellite-borne sensors do not usually achieve the overall accuracy of in-situ instruments, however their wide area coverage provides synoptic overviews that are denied any surface platforms (Allan, 1983). Satellite imagery used in this project provides same-day coverage of the region over which the space shuttle photographs were taken. This coincidental coverage allowed for easy, effective comparison of the thermal and surface structure of the water. A set of images

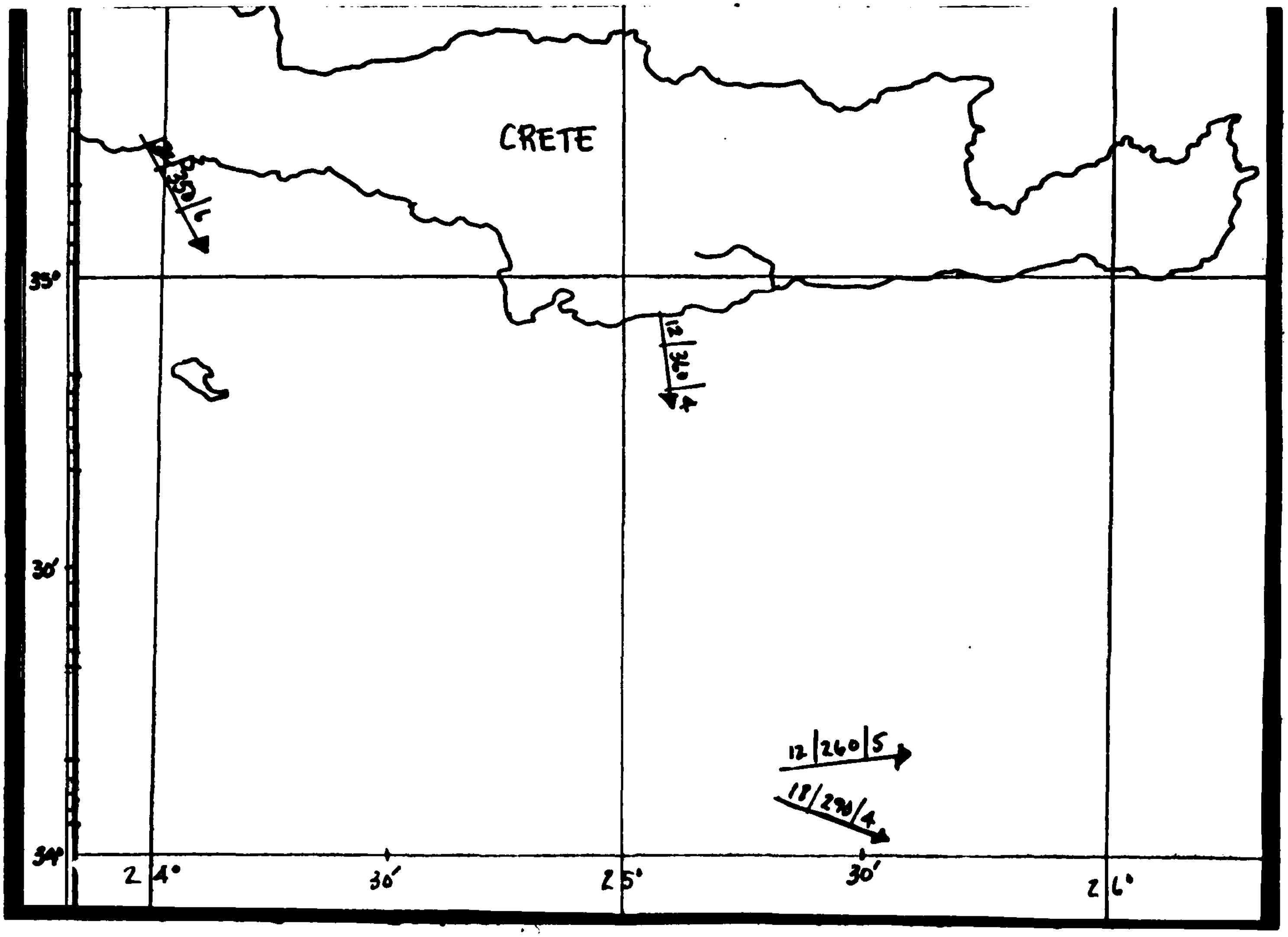



Figure 11 - Plot of local wind vectors for 7 and 8 October 1984. Arrows indicate location of measurement; first number on arrow indicates Greenwich Mean Time of the observation; second number indicates true direction of wind and third, the wind speed in meters per second.

covering 7 and 8 October was obtained from the satellite receiving station in Dundee, Scotland. These images were entered into a digital image processing system (DIPS) so that the area of interest could be enhanced. A one-degree grid of latitude and longitude was navigated onto the images along with a series of eight boxes delineating the region in the Levantine covered by the mosaic of shuttle photographs. Comparison of the shuttle photographs with the thermal IR satellite images would reveal any relationships between the temperature field and the visually observed swirl patterns. Figure 12(a) is a thermal IR image of the eastern Mediterreanean basin between Crete and Libya, taken on 7 October at 0300 local time. The various shades of gray in the image correspond to varying sea surface temperatures. In this image, gray-shade convention is reversed: higher temperatures appear brighter, while the lower temperatures are darker. Figure 12(b) is a thermal IR image of the same scene taken 24 hours later. A comparison of these two figures demonstrates that thermal features, such as the cold-core features at point 1, are persistent from one day to the next. This persistence identifies the patterns as stable features in the ocean's mixed layer, not temporary disturbances that change appearance and location

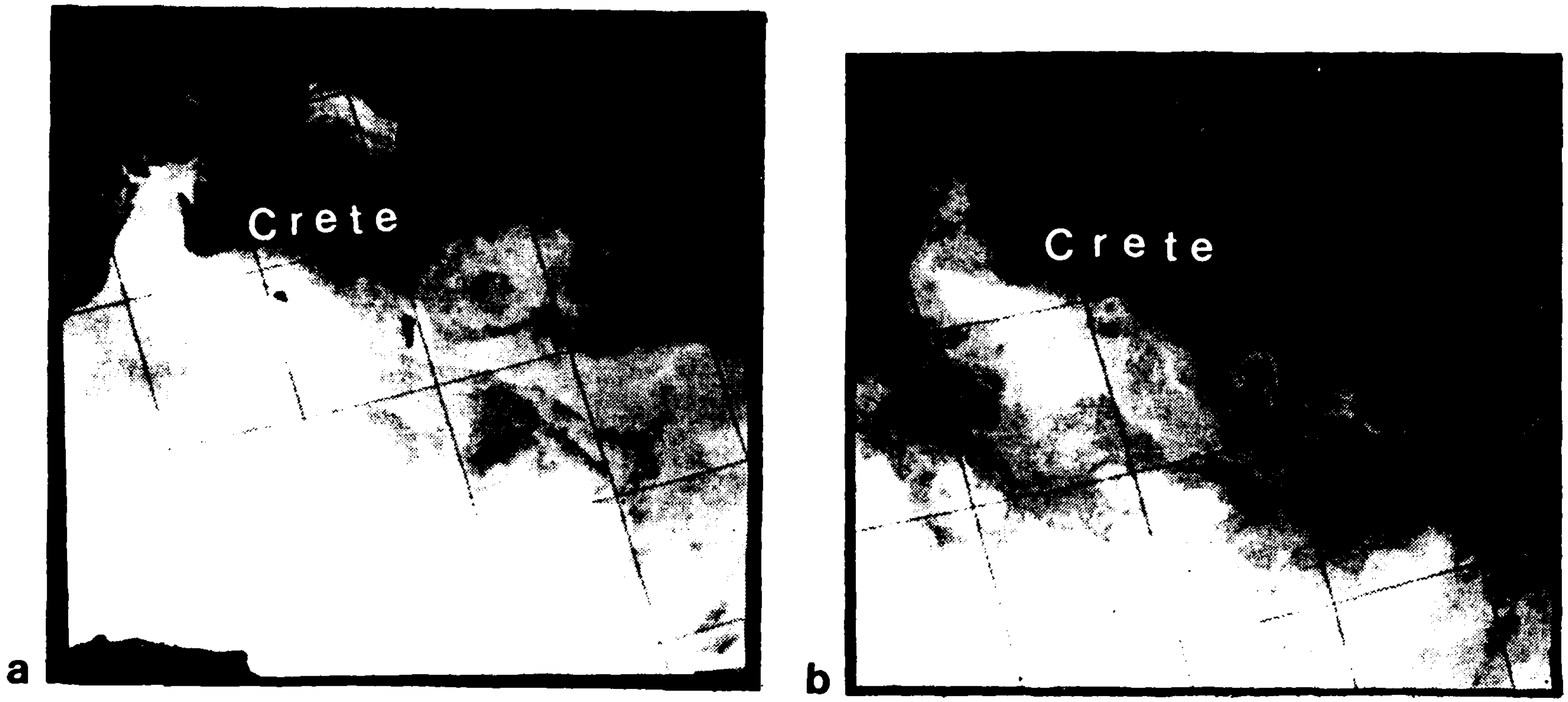



Figure 12 - Thermal infrared images of the Levantine Basin for (a) 7 October, (b) 8 October 1984. The surface marked at (1) in the left image corresponds to the surface feature identically marked in the right image.

based on local weather conditions.

The next step was to compare shuttle photographs with the thermal images for any correlation in eddy patterns. If the patterns in the photograph represented activity throughout some depth of the water column, these patterns would involve more than one water mass (i.e. cold and warm core eddies). These masses would have different characteristic temperatures, and the boundary between them would produce some signature in the thermal IR images. In order to intensify those boundaries, a gradient analysis was digitally performed on the two satellite images. The image in Figure 13 is the resulting contour representation of the thermal gradient on 8 October. The larger a change in temperature over distance on the sea surface, the greater the intensity of the signature in the gradient analysis.

Using the grid overlay on the mosaic of shuttle pictures, latitude and longitude of features of interest were determined. When these latitudes and longitudes were plotted on the thermal imagery, the positions were found to mark features of strong thermal gradient with visual characteristics similiar to the features in the photographs. Figure 11(a) is the second photograph in the series of eight that

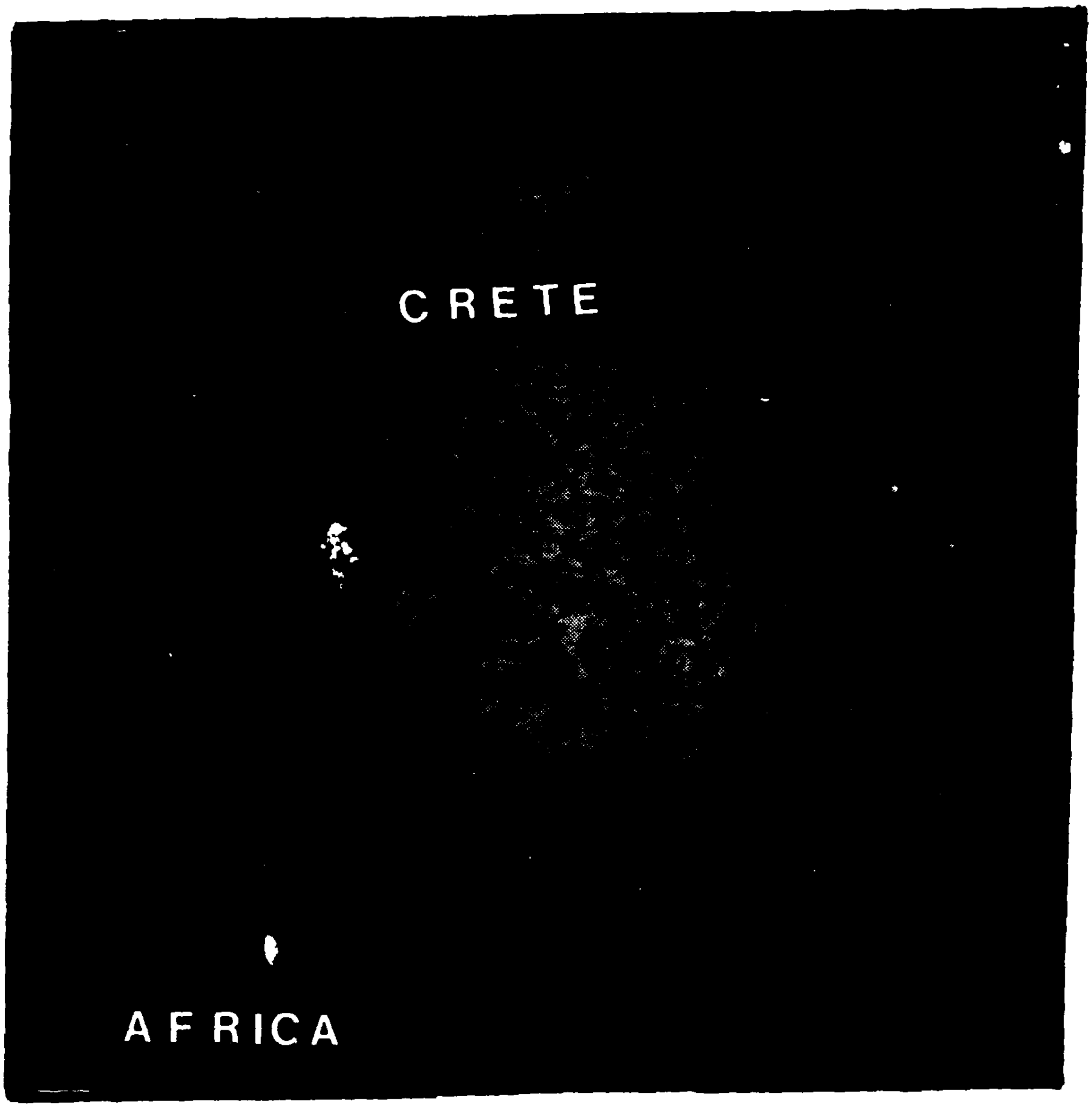



Figure 13 -Temperature gradient enhancement of satellite image in Figure 12(a).

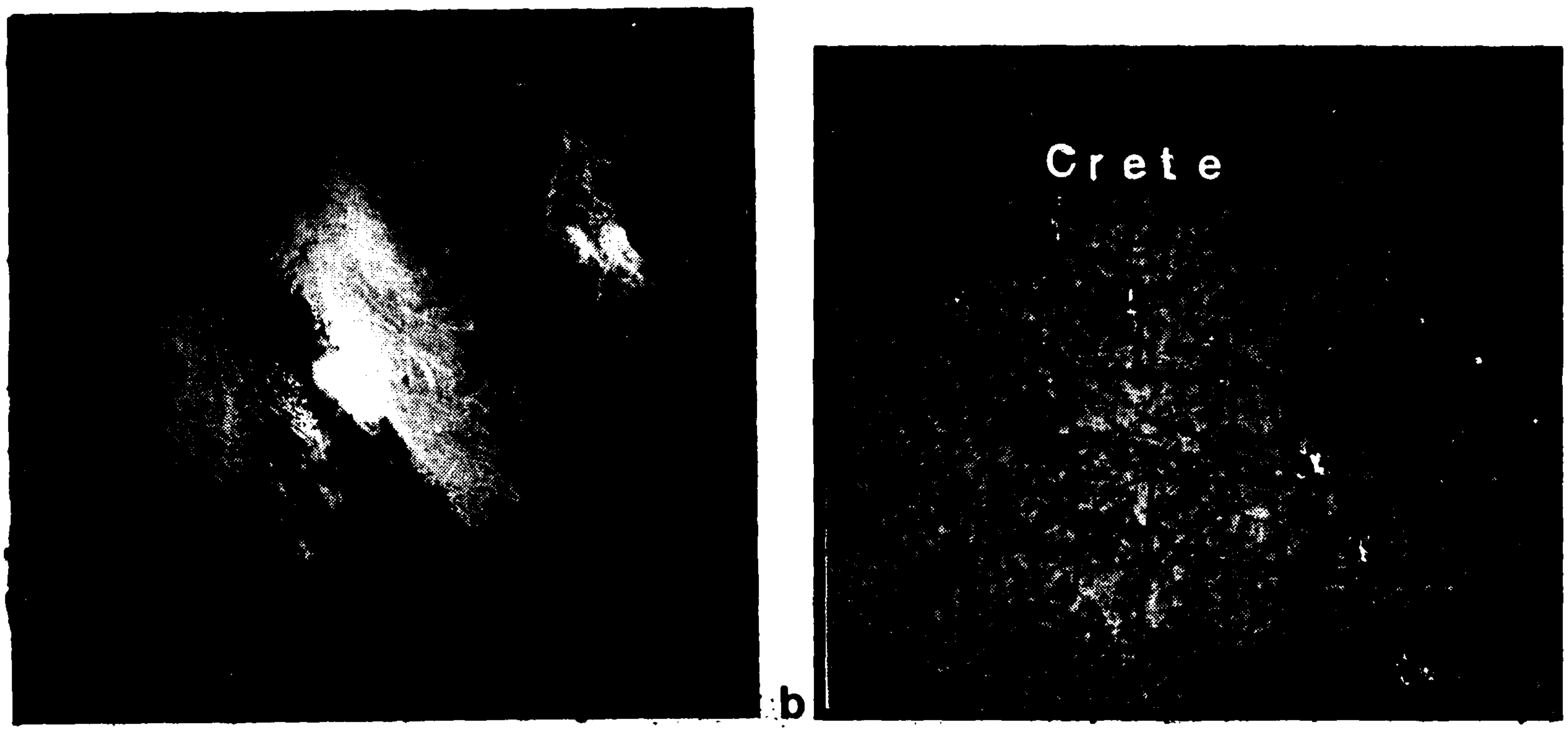
a
b



Figure 14 - The shuttle photograph in (a) corresponds to the position in the satellite image indicated by block b. Visual features at "a" in the photograph are represented in the thermal structure of the satellite image at "A".

compose the mosaic. It corresponds to the second northmost block in the satellite image displayed in Figure 14(b). When the latitude and longitude of the surface features marked at "a" in the shuttle photograph were plotted on the thermal imagery, they coincided with the thermal features at "A." Figure 15(a) is the third photograph in the mosaic. The linear feature at point "b" directly corresponded to the gradient feature at point "B" in the block "c" of the satellite image in Figure 15(b).

## IV. CONCLUSION

Sub-mesoscale eddies viewed in the eastern Mediterranean basin from the space shuttle Challenger on its STS 41-G mission appear to be the result of several interacting conditions. The first of these is a region of strong dynamics prone to changes in relative vorticity resulting in the generation or dissolution of cyclonic motion. These changes in vorticity are normally coincident with changes in the bathymetry of the basin, leading to the conclusion that the eddies are generated in the northern area of the basin around Crete. Flow in this region passes from the shallow water of the island-obstructed Aegean Sea through a narrow channel into

a

b

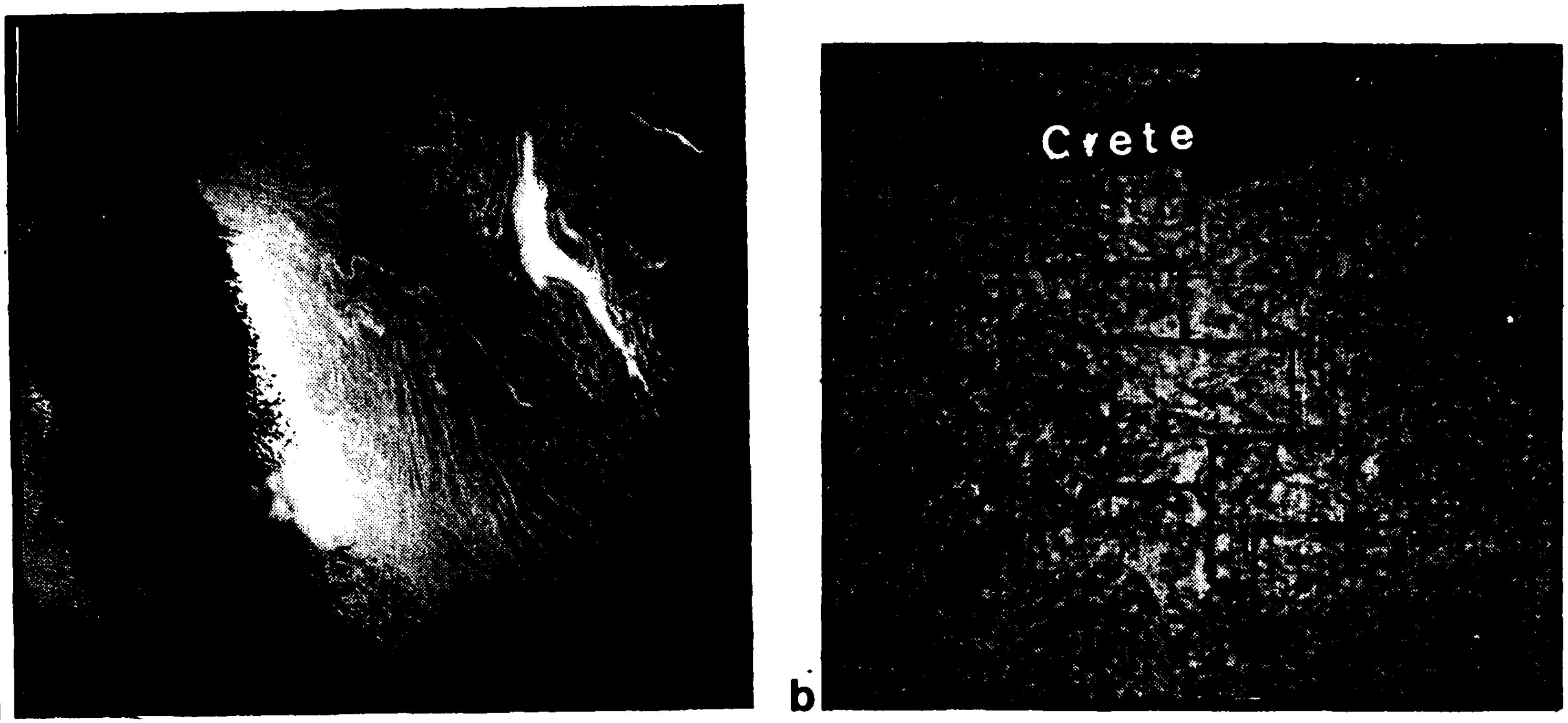



Figure 15 - The photograph in (a) corresponds to the position in the satellite image marked by block c. The surface feature indicated at "b" in the photograph corresponds with the thermal feature at "B" in the satellite image.

the wider, deeper Mediterranean basin. Additionally, the flow passing along the southern coast of Crete passes over a chain of seamounts; interactions of currents with changing bathymetry have been shown to cause a surface manifestation of the underwater bathymetry (Freise, 1986). Prevailing meteorological conditions, specifically local winds, did not interfere with the direction and strength of the eddy flow pattern in the case examined. Comparison of the space shuttle photography to satellite images of the same day reveals similarities in both individual features and overall pattern. These conditions suggest that spiral eddies are phenomena that are not restricted to the very shallow surface layer, but occur in the water column. They are, thus, more resistant to variabilities in local meteorology.

## V. PRACTICAL CONSEQUENCES AND INFLUENCES OF EDDIES

A knowledge of locations favoring formation of sub-mesoscale eddies and the effects of these eddies on the air-ocean environment has several practical applications in both the civilian and military arenas. Transport of heat, salt and nutrients by eddy processes may significantly alter population balances by inducing upwelling, concentrating these commodities in one area, or scattering them over another. To

fishing industries, remote-sensing of such ocean processes can help increase effective use of both time and money.

Of interest to the Navy is the effect of eddy disturbances on underwater acoustics. Any dynamic process that alters the mean ocean state will have an effect on sound propagation through that ocean. The representation of spiral eddies in the thermal structure of the satellite images indicates a variability of temperature in these areas. As the propagation of sound through the ocean is primarily a function of temperature in the first 1000 meters of the water column, acoustic systems will be affected by these eddy structures. If nothing else, these features introduce "noise" into the ocean environment.

## VI. RECOMMENDATIONS

One of the major obstacles encountered in utilizing the space shuttle photographs as a source of information was the difficulty in locating the position of the individual pictures. In pictures without any geographic reference points, the only point of location was the center of the photograph given in the data catalog. After the construction of the mosaic it was discovered that these center

points, however, ranged in accuracy from exactly accurate to as much as 100 km in error. The look angle of the shuttle varied from about 35 to 62 degrees causing distortion in the photographs. Even in photographs containing land features, this distortion made the latitude-longitude grid difficult and time consuming to overlay. In future shuttle missions, if a more definite and accurate means of recording location can be established when a photograph is taken, hand-held photographs would be a more convenient, more valuable source of visual information.

The thermal infrared images from the AVHRR of the NOAA-7 satellite provided a good deal of information. Ocean color data from the Coastal Zone Color Scanner (CZCS) might provide additional informative data, and a better delineation of the various water masses involved. These CZCS images should definitely be considered for applicability in subsequent eddy studies.

Finally, it is suggested that future shuttle communication of eddy location to on-site ships and aircraft could produce in-situ and time-dependent observations which could provide further insight into the nature of spiral eddies.

# APPENDIX A

An additional phase of research was conducted in order to produce a tangible appreciation of spiral eddies while applying proper research procedure. This phase was dedicated to constructing an experimental simulation of the eddy phenomena within a framework that allowed quantitative data collection coincidental with visual recording of surface features on photographic film. Specifically, a disturbance was generated in a test section of water through the introduction of a water jet. This disturbance would, it was thought, be manifested on the surface, creating a structure similar to that viewed in the space shuttle photographs. Capillary waves were introduced on the water's surface, by "wind" produced from low pressure air flowing into two adjacent manifolds. The output of air over the water was regulated by five valves on each of the manifolds. Light from four high intensity lamps was reflected off a solid white reflector onto the water's surface to simulate

the incident rays of the sun. The underwater disturbance would then be manifested in the resulting glint pattern, allowing it to be recorded on polaroid film. Wind and current velocity measurements were taken simultaneously from probes, thus producing a very general quantitative and qualitative foundation for any future, more precise simulations of the patterns.

An aluminum frame allowed for two-dimensional movement and near-exact positioning of a track and cart on which an underwater current meter was mounted. The depth of the current meter was variable, producing the ability to take measurements in three dimensions.

## I. Experimental Design

The first step was to produce a disturbance similar to the spiral eddies seen in the Mediterranean. As the Mediterranean is an enclosed sea, the best simulation should occur in an enclosed test region into which pump discharges introduced a flow. The final arrangement which produced the most acceptable spiral flow is shown in figure A-1. The flow in each trial arrangement of boundaries was tested and traced by red and blue dyes injected into

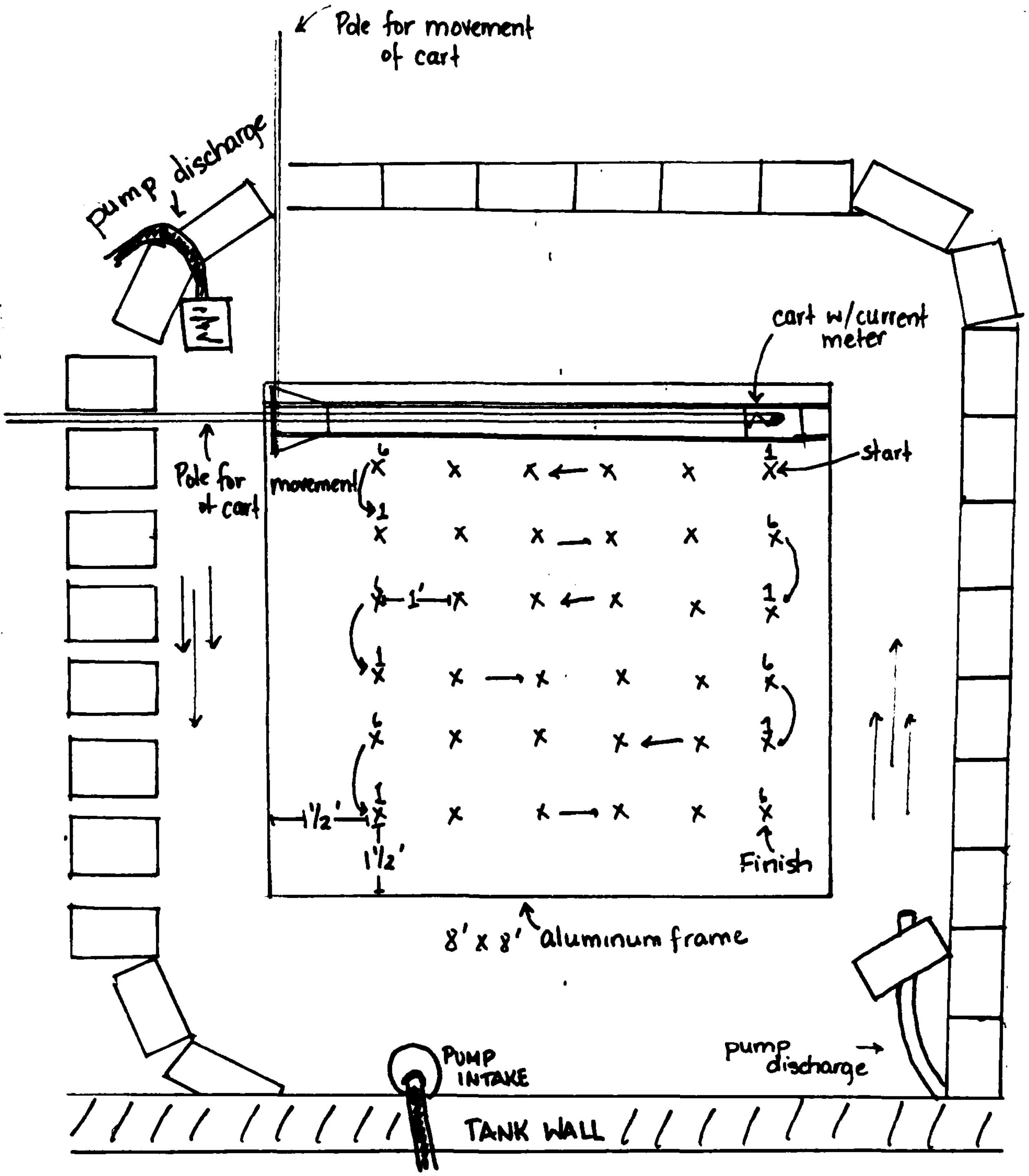



Figure A-1 Tank Arrangement. Within the enclosure of cinderblocks two pump discharges, flowing in the opposite direction, created a circular flow. The aluminum frame allowed positioning of the cart carrying the current meter. Each "x" marks point where velocity measurements were taken.

the water to see which produced the best spiral flow. Once the flow pattern was established, wind and lighting were added and measurements could be taken.

## II. Experimental Procedure

The first set of measurements was taken without the effect of wind, to determine the contribution of current alone on the surface patterns. Before each data collection period the water temperature and water level were recorded to make sure they remained constant. Measurements were taken in 15 inches of water at 15C. The current meter was originally positioned 3/4 inches below the water's surface in the far right corner where the first measurement was taken. Six readings were taken along each of the six rows at a spacing of one foot, with the outside points being one and a half feet from the frame. Each reading was taken 30 seconds after the cart had been moved to a new position to allow the water to settle. Measurements, plotted as vectors in the horizontal plane, produced a reasonable illustration of the horizontal velocity field of the water as indicated in Figure A-2. Attempts to record the surface manifestation of the spiral flow, however, were unsuccessful.

Both aluminum powder and talc, which float on the

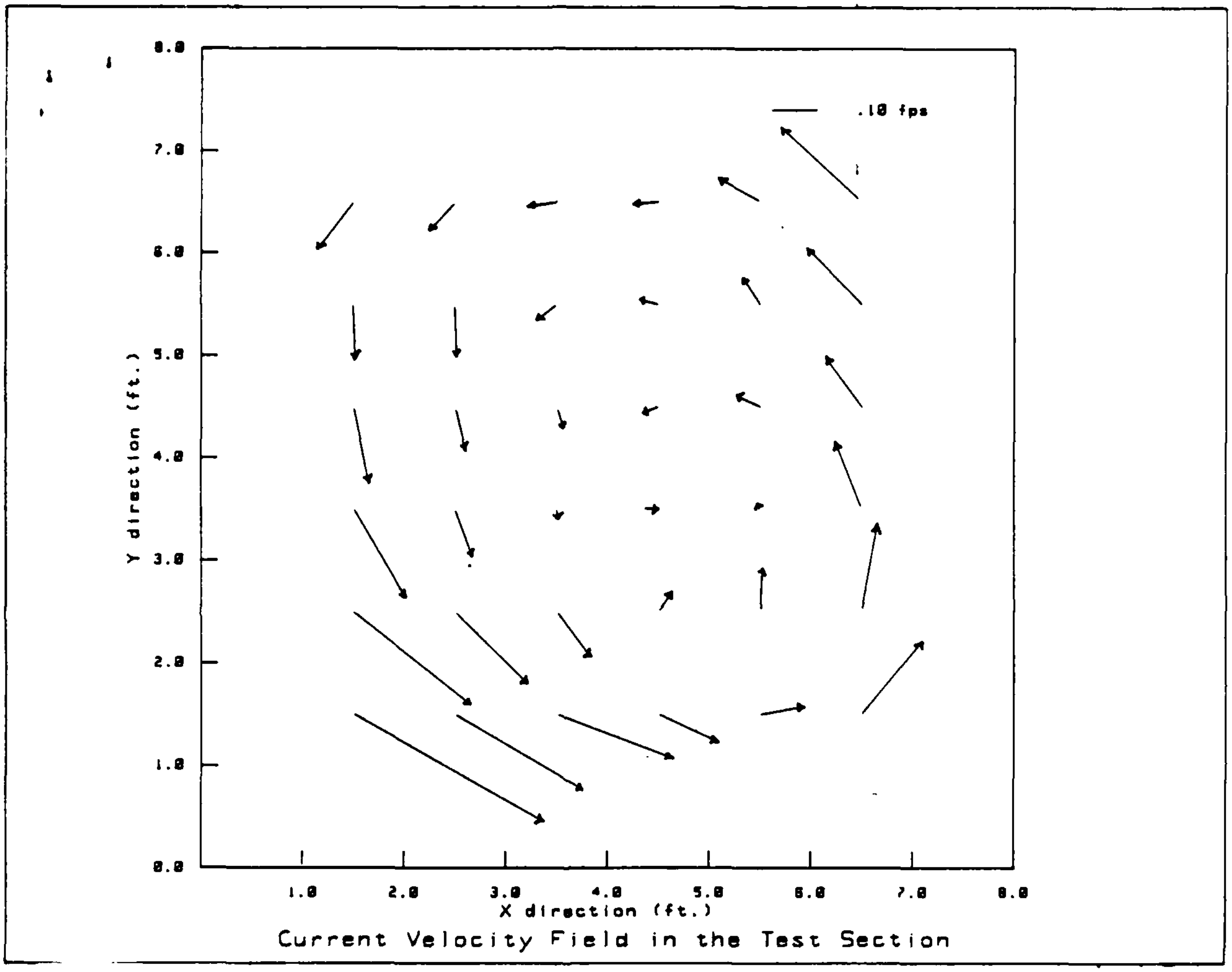



Figure A-2 Current Velocity field in the test section.

water's surface, were used as tracing agents in addition to the dyes. It was hypothesized that these agents would produce a more visible outline of the flow. When these methods were unsuccessful at producing a distinct image, two possible reasons for the failure were noted:

1) due to the water's transparency, reflections and patterns from the tank bottom interfered with the image;

2) each of the three agents traced only elements of the water's movement and not a continuous, well-defined eddy.

After the three prior methods proved unsuccessful, small amounts of oil were introduced into the test area with the belief that the oil would highlight convergent regions. Just as surfactants on the ocean's surface delineate convergent areas along the streaks of eddy patterns, it was hypothesized the oil would trace the eddy pattern by damping the surface roughness caused by the wind source, allowing the pattern to show up more distinctly on photographic film. The first oil tested was cod-liver oil. Although it proved too viscous to trace a swirl pattern, the oil emphasized the large contribution to surface movement made by the wind. As the oil droplets reached an area of

greater wind speed, they "piled up" and sheared off, circulating in a smaller spiral pattern driven more by wind than current. Mineral and lubricating oils were also tested. These also remained in drop form instead of spreading to trace a continuous flow pattern. Silicon oil, less viscous than previous oils tested, was also tested. Although the silicon oil tests did produce some image on the polaroid film, nothing comparable to the shuttle photographs was observed.

## III. Conclusion

The tank experiment simulated an area of almost uniform temperature, in which subsurface activity was driven by the induced current. The oil tests demonstrated the influence of the wind on the surface layer of water. Studies of ocean phenomena viewed from remote platforms requires a consideration of both surface and subsurface influences.

The shortcomings of the tank experiment lay in the inability to produce the many interacting conditions of the actual environment: no variable bathymetry was involved, no temperature gradients

existed and little actual scaling of the wind was possible.

# APPENDIX B

The list below contains the I.D. numbers of hand-held photographs used in this report, along with their corresponding figure numbers and the camera with which each was taken.

| Figure | Photograph I.D. | Camera |
|---|---|---|
| 1 | STS 200-046 | Linhof |
| 4 (1) | STS-35-85 | Hasselblad |
| (2) | STS-35-86 | " |
| (3) | STS-35-87 | " |
| 5 | STS-35-94 | " |
| 8 | STS-35-93 | " |
| 14 (a) | STS-35-86 | " |
| 15 (a) | STS-35-87 | " |

# ACKNOWLEDGMENTS

I had two major objectives in doing this research project. The first was to learn and apply proper research procedure. This involved collecting background information, analyzing this information and conducting an experiment based on that analysis. Inevitably incorrect assumptions were made, or unexpected results produced, and after reevaluating, a new tack had to be taken. The key to persisting through each "false start" was found in the second objective -- knowing where to go for help. I am most fortunate that my research field is one where help seems always freely and enthusiastically given. A wide variety of people have provided answers, materials, data and their valuable time when I had none of the above. I would like to acknowledge these people without whom this project would not have materialized.

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laboratory staff who were there to assist from creation to completion.

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